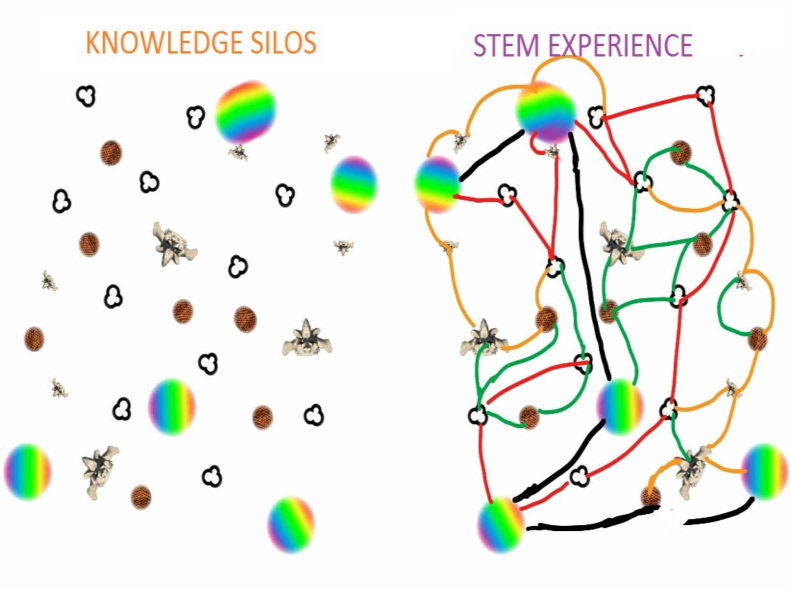
The STEM Mindset



INTERIM REPORT OF THE WORKING COMMITTEE ON STEM EDUCATION 2017

Transforming Knowledge Silos to STEM Experience

ABSTRACT

STEM Education in Schools is the only way we foresee to bring up a future ready workforce in the face of severe challenges for sustainable economic growth. STEM Education would provide the integrated mindset for the new generation to tackle real life problems with real solutions.

THE STEM COMMITTEE

National Science Foundation

INTERIM REPORT OF THE WORKING COMMITTEE ON STEM EDUCATION

TABLE OF CONTENTS

NATIONAL SCIENCE FOUNDATION

INTERIM REPORT OF THE WORKING COMMITTEE ON STEM EDUCATION

TABLE OF FIGURES

INTERIM REPORT OF THE WORKING COMMITTEE ON STEM EDUCATION

RECOMMENDATIONS OF THE STEM COMMITTEE

NATIONAL SCIENCE FOUNDATION

NATIONAL SCIENCE FOUNDATION

24 September 2017

Vidya Mawatha

Colombo 7

Sri Lanka

NATIONAL SCIENCE FOUNDATION

EXECUTIVE SUMMARY

This report is the outcome of 14 meetings and 02 workshops conducted by the STEM Committee since May 2016. The Chairperson appointed a WORKING COMMITTEE ON SCIENCE, MATHEMATICS AND ENGINEERING EDUCATION. This was referred to as the STEM Committee. The Committee discussed the curricula, teaching, training, processes and outcomes of STEM education in the school system within the TOR. This is an interim report focusing only on the School education aspects of STEM.

There is unanimity on the major impact STEM education will have on the economy by preparing a workforce ready for the future challenges. Among the challenges that we face soon are due to trade liberalization globally and technology adoption locally while there is a technology revolution going beneath the 4th industrial revolution. Our country being at the efficiency driven level in the global competitiveness should fast adopt technology to improve on production and along with it an equally well STEM educated workforce is required.

STEM related subjects are taught in silos at schools and it requires modern methods of integrated learning to change the mindset of learners. The real-life solutions are seen possible and arise due to the integrated thinking habits. The curricula of Science, Technology and Mathematics carry many opportunities that could delve deep into the STEM integrated learning process and requires developing pedagogies for teaching.

Engineering is not a subject in schools but through the STEM learning processes it will automatically get introduced through the problems and working out solutions. These solutions have a thought process that will generate the development of Engineering cognizance.

Teacher training is as important as curriculum adjustment. The teachers should get trained on providing many practical problems that are multidisciplinary and requires collaboration with other teachers of different disciplines. Hence teachers' mindset also needs treatment in the STEM introductory process.

Current evaluations do not meet with the requirements of STEM education. STEM develops through the continuous journey on facing experimental work and finding solutions to problems. In their search for solutions students make many failures and attempt new strategies to solve these problems which eventually may succeed. Failures are not considered in STEM education as failures but pillars of success and hence must be assessed with due respect. Only a strong School Based Assessment system can meet this challenge

Finally, we are convinced about the benefits of using subjects other than STEM in the same philosophy as adopting STEM into the system. The philosophy being that there can be successful solutions to real-life problems only when knowledge is multidisciplinary. In this situation we recommend English, Aesthetics, Arts, Humanities and particularly Economics.

NATIONAL SCIENCE FOUNDATION

THE STEM COMMITTEE

MEMBERS OF THE STEM COMMITTEE

Dr. Chandra Embuldeniya – Co Chairman

Prof. Sunethra Karunaratne

Dr. Gunadya Bandarage

Prof. Jayantha Wijeratne

Mrs. Priyatha Nanayakkara

Ms. Damayanthi Balasuriya

Mr. Vipula Kulathunga

Mr Sydney Jayawardena (Co-Chairman) (until Aug 2017

Mr B.D. Chiththananda Biyanwila (until December 2016)

Mr K.G. Janaka Karunasena, Additional Director (Covering)

Ms Maduka Senaratne, Scientific Officer, Secretary

TOR OF THE STEM COMMITTEE

1. Identify the needs & gaps to make suitable recommendations to enhance the popularity of subject disciplines like science, mathematics and engineering with equitable access among students
    - Human resources with necessary skills and attributes
    - S &T infrastructure and necessary benchmarking
2. In partnership with Ministry of Education (MoE) and Universities recommend, facilitate and promote research on different aspects of learning/teaching science, mathematics and engineering facilitate operationalization of research outcomes.
3. Recommend programmes or activities for communication of science, mathematics and engineering education issues to relevant stakeholders as appropriate.

    a. Facilitate networking among peers and other relevant stakeholders using electronic and other means.

    b. Enhance public awareness and understanding of the importance of relevant areas in partnership with the NSF Working Committee on Science Popularization.

NATIONAL SCIENCE FOUNDATION

c. Help the establishment and development of outreach activities including web presence and internet web pages that can enthuse school children and attract industry take up of basic research from within the academic community.

d. Create/ promote understanding & awareness about the importance of S & T and innovation in nation building and on career opportunities in Science in partnership with NSF Working Committee on Science Popularization.

e. In collaboration with the NSF Working Committee on Science Popularization, MoE and Universities encourage to organize science camps and science exhibitions focusing on different learner communities on science, mathematics and engineering disciplines in Sri Lanka.

4. Advise the NSF on priority issues to be communicated to policy makers on a timely basis.

5. Propose and facilitate mechanisms to attract the younger generation into science disciplines and science careers in collaboration with the NSF Working Committee on Science Popularization.

6. In collaboration with the MoE,

- Facilitate the establishment of links between schools, research institutes and industries to appreciate scientific concepts and encourage innovative thinking.
- Identify and facilitate international partnership for twining arrangements and identifying funding opportunities to improve learning and teaching science at all levels.

7. Coordinate, collaborate and cooperate with other institutions and agencies on national, regional and international activities related to science, mathematics and engineering education at the request of the BoM.

8. Provide necessary support and guidance on issues referred by the BoM /Director on NSF programmes and divisional activities at their request.

NATIONAL SCIENCE FOUNDATION

INTERIM REPORT OF THE WORKING COMMITTEE ON STEM EDUCATION

1. DEFINITION OF STEM

STEM is an acronym used to represent the initials of the four subjects, Science, Technology, Engineering and Mathematics. There is no single subject labelled as STEM[1]. We could define *STEM as a* ***multidisciplinary stream of experience relevant in the economic value creation[2] and live in harmony with nature***. In the education system STEM is relevant for studies beginning from preschool to postdoctoral levels[3]. This concept is practically essential to work out solutions in real life situations.

This approach to education is aimed at revolutionizing the teaching of subject areas such as mathematics and science by incorporating technology and engineering into regular curriculum by creating a "meta-discipline." STEM Education attempts to transform the typical teacher-centred classroom by encouraging a curriculum that is driven by problem-solving, discovery, exploratory learning, and require students to actively engage a situation to find its solutions to the problems.

1.1. Introduction to STEM Constituents

Science is the intellectual and practical activity encompassing the systematic study of the structure and behaviour of the physical and natural world through observation and experiment. It is the study of the natural world. At school level **Science** is made up of **Chemistry**, **Physics**, and **Biology**. **Chemistry** is the branch of science concerned with the substances of which matter is composed, the investigation of their properties and reactions, and the use of such reactions to form new substances. **Chemistry** has many branches including **Organic Chemistry**, **Inorganic Chemistry** or **Physical Chemistry**. **Technology** is the branch of knowledge dealing with engineering or applied sciences. **Technology** is a subject in our education system and a stream of education in our senior secondary and postsecondary education system. Technology includes any product made by humans to meet a want or need. A chair, a pencil or a mobile phone are

---

[1]STEM education was started by Judith A. Ramaley, a former Director of the USA National Science Foundation's Education and Human-Resources Division.
[2] NSF Working Committee on STEM Education, Jul 2017.
[3] Science, Technology, Engineering, and Mathematics (STEM) Education: A Primer. Congressional Research Service. Heather B. Gonzalez, Specialist in Science and Technology Policy. Jeffrey J. Kuenzi, Specialist in Education Policy, August 1, 2012.

technologies. Any product students create to solve a problem can be regarded as technology. Technology can be an outcome of Engineering. Technologies are valuable tools in Engineering, Science and Mathematics. STEM subjects are interconnected and the STEM teaching is responsible for the creation of such a mindset in students.

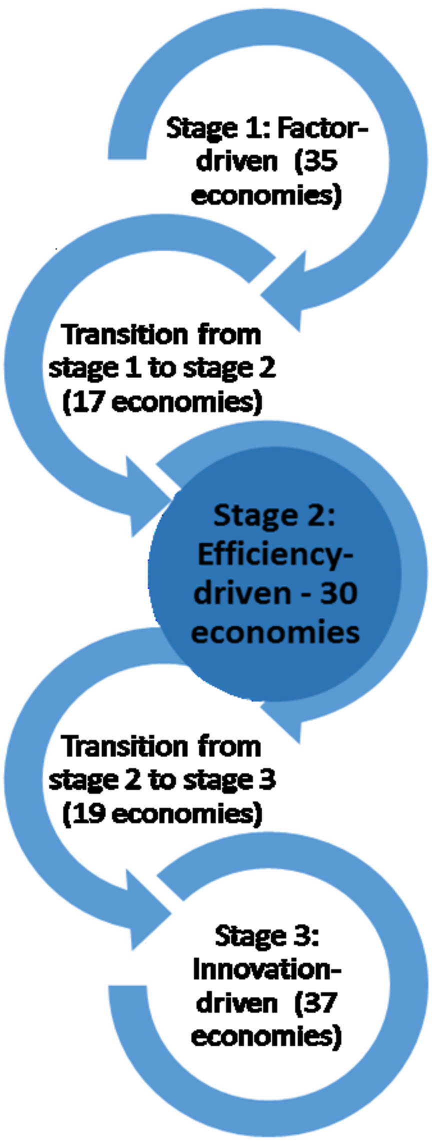
Biology is the study of living organisms, divided into many specialized fields that cover their morphology, physiology, anatomy, behaviour, origin, and distribution. **Biology** is made up of **Botany** and **Zoology**. **Botany** is the scientific study of the physiology, structure, genetics, ecology, distribution, classification, and economic importance of plants, and **Zoology**, the scientific study of the behaviour, structure, physiology, classification, and distribution of animals. **Mathematics** is the language of numbers, shapes, and quantities that seems so irrelevant to many students. It is the abstract science of number, quantity, and space, either as abstract concepts (pure mathematics), or as applied in science and engineering (applied mathematics). **Engineering** is tangible and based on outcomes of designs using the mix of sciences. **Engineering** is the branch of **Science** and **technology** concerned with the design, building, and use of engines, machines, and structures. **Technology** has a mix of engineering and science. **Technology** is the application of scientific knowledge for practical purposes, especially in industry.

2. STEM RELEVANCE TO SRI LANKA

2.1. Competitiveness

The World Economic Forum Competitiveness Report 2016-17, gives some good indications for us to be mindful about the competitive situation of Sri Lanka. This is important since we are preparing a future ready generation for taking up the economic challenges in production and growth. Our competitiveness vis a vis the rest of the world therefore is of paramount importance to attract investments and develop the country. The position is shown in a nutshell below. The report shows that we have vacillated around the 65th out of 148 countries to 71st out of 138 countries in the recent assessment. We are in the Efficiency driven stage of the development where the important pillars are Basic Requirements (40%) and Efficiency Enhancers (50%). This situation was further analysed to understand details. Sixty assessment pillars taken for this study have got worse in case of Sri Lanka during the year while 9 remained static and 45 improved. The net result was seen in our rank dropping down from 68 out of 140 countries to 71 out of 138 countries. Some of the key factors relevant in an education context follows. The factors having a direct impact on education are given below.

Figure 1 World Economic Forum Classification of Countries at Different Stages of Development



4.09 Quality of primary education,
5.03 Quality of the education system,
5.01 Secondary education enrolment rate gross %,
5.05 Quality of management schools,
5.07 Local availability of specialized training services,
5.04 Quality of math and science education,
5.02 Tertiary education enrolment rate gross %,
5.06 Internet access in schools, and
5.08 Extent of staff training

These factors must be dealt from the education side at primary secondary and tertiary levels.

Figure 3 Changes in Competitiveness Pillars 2016-2017

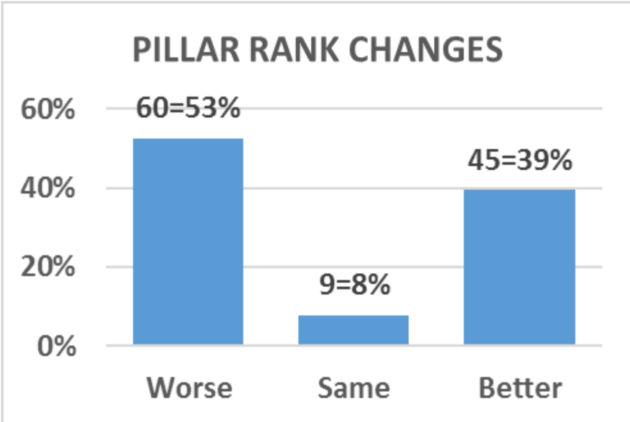
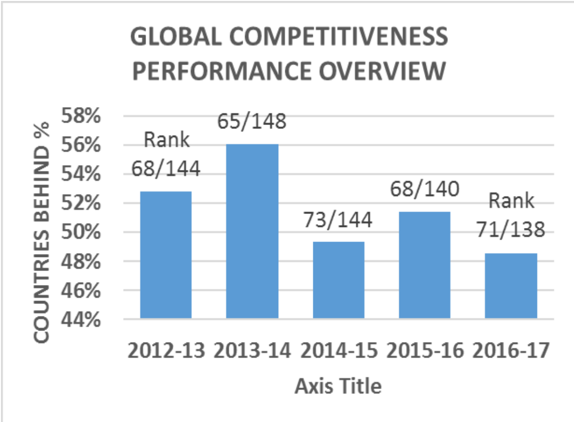


Figure 3 Sri Lanka's Competitiveness Rankings



Source: Analysis of WEF GCI Reports 2015/16, 2016/17

2.2. Human Capital Development

Another report that indicates gives us good indications are the **WEF Human Capital Report 2016 (page 10).** This report provides an Index that covers six countries from the South Asia region: Sri Lanka (50), Bhutan (91), Bangladesh (104), India (105), Nepal (108) and Pakistan (118). The overall average score for the region is 59.92—behind the Middle East and North Africa and ahead of Sub-Saharan Africa—and all but the top two have yet to reach the 60% threshold regarding optimizing their human capital potential.

The bright spot for the region, Sri Lanka (50), benefits from strong educational enrolment and basic education completion rates as well as positive perceptions of the quality of its primary schools and education system overall (23rd on both). However, it underperforms when it comes to translating the potential of its young population to the workforce, with one in four young

Figure 4 Sri Lanka is in the Efficiency Driven Stage

people not active in employment, education or training. This gives an indication of our gaps in education.

RECOMMENDATION 1: Education must be planned to enable moving up the STEM ladder. WEF Report 2016-17 and the WEF Human Capital Report 2016 has indicators where we should focus to improve on global competitiveness.

Since 2001, STEM letters have been a part of educational vocabulary but it did not translate into an active process. Our learning process is dependent on silo based curricula of individual subjects. These are taught in the classroom and students cram up what is taught. Teachers specialize in individual subjects and do not necessarily have the insights of multidisciplinary work.

At school level Science is made up of Chemistry, Physics, and Biology. Technology is a subject in our education system and a stream of education in our senior secondary and postsecondary education system. Engineering has a mix of science and technology while technology has a mix of engineering and science. Science prepares the student with the foundation for both engineering and technology. Mathematics gives the basis for justification of the concepts and solutions practically arising from the interactive knowledge of these subjects.

In real life, these silos of knowledge are mixed in applications to solve problems to produce comforts and benefits to society. In the learning processes, today, students learn without cognitive stimulation. They regurgitate the knowledge gained in different silos. Application of silo based knowledge in real life rarely happens. At most the students learn to solve problems which have been the subjects of study in a classroom setting but not in real life practice. The worst outcome of this situation is the low level of technological development of the economy. It is also evident from the low level of competitiveness and the factors that have contributed to drastically bring down the rankings of the country. We are also a nation poor in innovation as innovations require a high level of intellectual stimulation in the interaction of STEM subjects.

To apply such knowledge in real life, the mindset of students should relate science with technology, mathematics with science, and mathematics with technology. Engineering Designs would arise with integrated knowledge of these subjects. These involve thinking in multi disciplines and working in teams. The aim of STEM education is to produce such a mindset among the students.

RECOMMENDATION 2: Silo based thinking should be changed to integrated thinking to develop STEM education, which translates into real life solutions to problems.

In Sri Lanka, there were so many educational reforms related to science. Science was introduced to the school system in the last quarter of the19th century by British rulers only to privileged schools in urban areas. Since independence there was an expansion of science instruction, but even in the late 1960s science was taught in a limited number of schools. Reforms in 1972 focused on building up science concepts related to lives of students. With the implementation of "Science for all" project, science was made compulsory to learn by all students from grades 6 to grade 10. At primary level science was taught as "Beginning science" for grades 3 & 4 to prepare students to learn science from grade 6. The reforms in 1997 introduced a new subject "Environment Related Activities (ERA)". It is an integrated subject of science, physical education, aesthetic education and oral English. In grade 6, science was taught under "Environmental Science" and from grades 7-11 as science and technology. Although reforms were introduced to make science to be useful to everybody, students were not able to use science that they have learnt in their everyday experiences. UNESCO (1985) has also reported that in the developing countries, only a limited number was able to apply science. This knowledge gap has hindered the social and economic development of the country.

RECOMMENDATION 3: Science has not been used on a day to day basis by the large majority. The STEM education should make it possible to develop and implement solutions to day-to--day problems.

"Sri Lanka's aspiration to rise to an Upper Middle Income Country status depends on how skilled and versatile its people are," said Idah Z. Pswarayi-Riddihough, World Bank County Director for Sri Lanka and Maldives. "The higher education system must produce a pool of highly skilled scientists, engineers, doctors, entrepreneurs, policy makers, academics, and teachers, who can contribute to sustainable economic development of the country. Improving competitiveness and growth of the country is a key focus of the Sri Lankan Government and we are pleased to be supporting them in this endeavor."

The World Bank in a recent report indicated that STEM education is a must for Sri Lanka.[4] [5] The country fares poorly in the proportion of students enrolled in subjects of vital importance for economic development, such as the sciences, technology, engineering, and mathematics (STEM). The proportion of students in the sciences was just 13 percent in 2014. For engineering alone, with an enrolment share of 7 percent, Sri Lanka fares even worse, at 69th of 79 countries for which data were available[6].

---

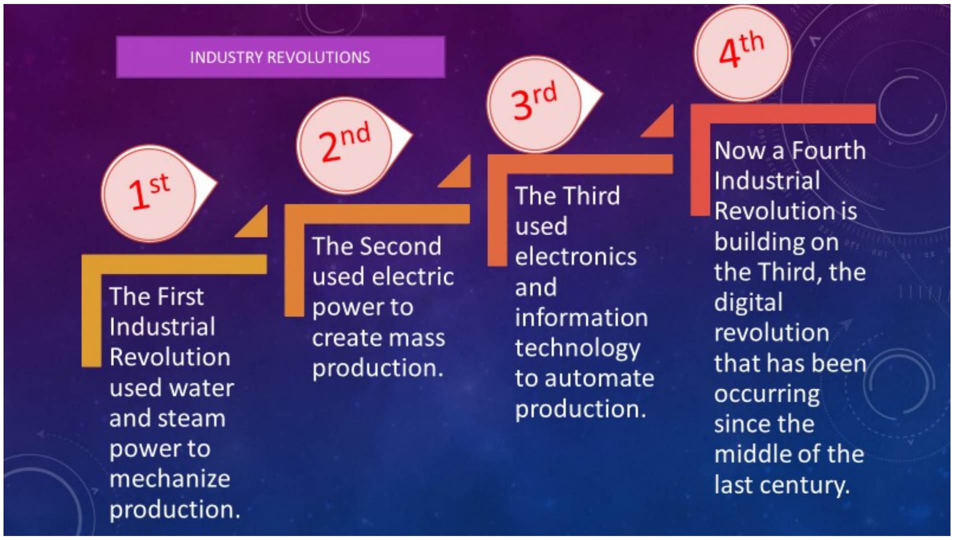
[4] http://www.worldbank.org/en/news/press-release/2017/05/12/sri-lanka-improve-higher-education-with-world-bank-support

[5] http://documents.worldbank.org/curated/en/258231494813658621/pdf/SRI-LANKA-PAD-04252017.pdf

[6] WB Report NO: PAD2183. PROGRAM APPRAISAL DOCUMENT, ACCELERATING HIGHER EDUCATION EXPANSION AND DEVELOPMENT OPERATION APRIL 17, 2017. Sri Lanka's higher education sector needs considerable future development. With a gross enrollment ratio (GER) of 21 percent, the country has higher education enrollments well below those of UMICs, which have an average GER of 44 percent, and below even the average for LMICs of 23 percent. Further, slightly more than 50 percent of Sri Lanka's higher education students are enrolled in external degree programs (EDPs), where they register and face examinations in a university, but do not follow lectures and classes and do not receive real academic support from the university. This means that Sri Lanka's effective GER is

WB report states, Females account for 62 percent of undergraduate enrolments. However, while females are heavily represented in the arts, humanities, and education fields, in the STEM programs, the share of male and female students is about equal, with 49 percent of university enrolments in STEM programs being female students. Once students enrol in universities, the degree completion rate is very high. For instance, in STEM programs, the rate is over 98 percent. The key challenge, however, is the small proportion of students enrolled in universities and higher education institutions (HEIs). Sri Lanka needs to urgently increase higher education enrolment with a special focus on degree programs, especially STEM degree programs, which are critical for future economic growth through higher-value-added industries and services.

Figure 5: Fourth Industrial Revolution is Digital



Expanding enrolment in higher education with a special focus on the STEM subjects will increase opportunities for young people, including youth from rural and estate sector families, to obtain jobs with higher remuneration. In addition, the World Bank's Systematic Country Diagnostic (2014) Report No. 99891 identified the development of the higher education sector, particularly increasing the enrolment of STEM students and promoting research and innovation, as key areas for Sri Lanka's future development.

The WB has emphasized the need to have more STEM and equity in gender in STEM education. It is also connected well with future development of Sri Lanka through technology oriented job creation. The relevance of STEM is in no way uncertain.

RECOMMENDATION 4: As the World Bank has stated unequivocally, to have more STEM and equity in gender in STEM education.
RECOMMENDATION 5: World Bank stated more enrolment in STEM education is urgent for economic development to create STEM related industries and services. Increase intake in STEM related degree programs to facilitate human capital needed for STEM dependent industries.

closer to 10 percent. Overall, in 2014, Sri Lanka was ranked 88th of 115 countries for higher education participation. The same year, among East Asian countries that Sri Lanka aims to emulate, Malaysia's GER was 28 percent, Indonesia's GER was 31 percent, and Thailand's GER was 53 percent. 2.

3. STATUS OF STEM SUBJECTS

At present in our school curriculum science, mathematics and technology are included as separate subjects and engineering is not a subject. These three subjects have different syllabuses and curricula without an integration of concepts of subjects for the development of many competencies. STEM is more than just a grouping of subject areas. It is a movement to develop the deep mathematical and scientific underpinnings students need to be competitive in the 21st-century workforce, but goes far beyond preparing students for specific jobs. STEM develops a set of thinking, reasoning, teamwork, investigative and, creative skills that students can use in all areas of their lives. STEM isn't a standalone class—it's a way to intentionally incorporate different subjects across an existing curriculum.

RECOMMENDATION 6: STEM is not a standalone class – it is a way to intentionally incorporate different subjects across an EXISTING CURRICULUM. Teaching of STEM should reflect this fact.

Science is taught in schools as a subject from Grade 6 up to Grade 11. Science is taught as a disciplinary mix of Chemistry, Physics and Biology. At present, science is taught at primary level under the subject, "Environment Related Activities (ERA)" through 15 themes. From grades 6-11, science is taught as one subject and it is one of the core subjects at GCE (O-L) examination. The concepts of biology, chemistry, physics and earth science are taught under separate components in science and, there is no integration even among these components in science. Instead of building up concepts, many students develop misconceptions in science. Hence, it is difficult for students to see the linkages among science concepts and how these are related to day-to-day life. They will find it more difficult to see the relevance of other subjects to be successful in their education. Those who will not be able to continue learning science at GCE (A-L) or dropped out from school at GCE (O-L) would not use what they have learnt as science for everyday life and in their work places. By introducing STEM all students will develop an understanding of science, mathematics, engineering and technology and why they must learn the content in STEM.

RECOMMENDATION 7: The Science taught in schools today (up to O-L) is done in subject silos with no integration of concepts. School leavers rarely would use what they have learnt as science for everyday life. STEM education should be introduced to change this situation.

3.1. Six characteristics of a great STEM lesson

STEM lessons often seem like science lessons and experiments, and in some ways, they are. After all, genuine science experiences are hands-on and inquiry-based, but in an "ideal" STEM lesson, there are some substantial differences. Six characteristics of a great STEM lesson proposed by Anne Jolly[7] are given below:

[7] Ann Jolly is a STEM Consultant co-developed nationally recognized STEM curriculum with support from the US Science Foundation, http://www.stem-by-design.com/tag/anne-jolly/

1. **STEM lessons focus on real-world issues and problems**. In STEM lessons, students address real social, economic, and environmental problems and seek solutions. The engagement of students in STEM activities enables students not only to develop knowledge, but also several soft skills.

2. **STEM lessons are guided by the engineering design process**. The EDP[8] provides a flexible process that takes students from identifying a problem—or a design challenge—to creating and developing a solution. In this process, students define problems, conduct background research, develop multiple ideas for solutions, develop and create a prototype, and then test, evaluate, and redesign them. This sounds a little like the scientific method—but during the EDP, teams of students try their own research-based ideas, take different approaches, make mistakes, accept and learn from them, and try again. Their focus is on developing solutions.

3. STEM lessons immerse students in hands-on inquiry and open-ended exploration. In STEM lessons, the path to learning is open-ended, within constraints. (Constraints generally involve things like available materials.) The students' work is hands-on and collaborative, and decisions about solutions are student-generated. Students communicate to share ideas and redesign their prototypes as needed. They control their own ideas and design their own investigations.

4. STEM lessons involve students in productive teamwork. Helping students work together as a productive team is never an easy job. It becomes exponentially easier if all STEM teachers at a school work together to implement teamwork, using the same language, procedures, and expectations for students.

5. STEM lessons apply rigorous mathematics and science content in their learning. In STEM lessons, it is necessary to connect and integrate content from mathematics and science courses. Plan to collaborate with other mathematics and/or science teachers to gain insight into how course objectives can be interwoven in each lesson. Students can then begin to see that science and mathematics are not isolated subjects, but work together to solve problems. This adds relevance to their mathematics and science learning. In STEM, students also use technology in appropriate ways and design their own products (also technologies).

Best case scenario: Involve an art teacher as well. Art plays a critical role in product design. Teams will want their products to be attractive, appealing, and marketable. When the arts are added, the STEM acronym becomes STEAM.

6. STEM lessons allow for multiple right answers and reframe failure as a necessary part of learning. STEM classes always provide opportunity for multiple right answers and approaches. The STEM environment offers rich possibilities for creative solutions. When designing and testing prototypes, teams may flounder and fail to solve the problem. That's okay. They are

---

[8] External Degree Programs

expected to learn from what went wrong, and try again. Failure is considered a positive step on the way to discovering and designing solutions.

RECOMMENDATION 8: STEM experience should be designed bearing the following six characteristics in mind – a) Focus on real world issues, b) Guided by the engineering design process, c) Hands on inquiry and open-ended exploration, d) Productive team work, e) Collaboration among teachers to bring rigorous math and science content in, f) Allow multiple right answers and failures as a necessity of learning

NATIONAL SCIENCE FOUNDATION

4. ASSESSMENTS IN STEM

There is no assessment of STEM education currently. STEM is a learning experience and a mindset created by the integrated knowledge from the relevant subjects. As such outcomes should be assessed rather than evaluated by a school based term end test or by the CGE as a common test for all schools. Assessment of STEM is a continuous process bearing in mind the possibility of multiple outcomes and taking account of failures as a pillar of STEM learning. This is a major challenge but clearly a possibility under the School Base Assessment (SBA). SBA has to be re-engineered to match the philosophy and the outcomes of STEM education.

RECOMMENDATION 9: STEM outcomes should be continuously assessed by the school teachers engaged in teaching STEM subjects

School-based assessment has been introduced to the school system with the education reforms in 1997. In 2008, a guidebook[9] has been disseminated to all schools introducing 23 modalities of assessment. Research shows that schools do not practice these properly and there is a need to train teachers on why, when and how to use different modalities. SBA is not considered for the final results of GCE (O-L & A-L). Hence, teachers do not pay much attention on SBA activities. Of the 23 modalities, if teachers concentrate at least on portfolio assessment there will be an improvement in student achievement. These modalities can be used in STEM classes and, there should be 60% weightage for SBA and 40% to the final closed-book examination.

RECOMMENDATION 10: Re-engineered SBA should carry 60% weight to measure outcome of a student in STEM education. SBA should be in line with SLQF (Sri Lanka Qualification Framework)

STEM ideas would become connected to all curricula. As a result, it would not be necessary to have a public examination and schools can award a certificate based on SBA in conformity with Sri Lanka Qualification Credit Framework with effective monitoring from administrative staff of educational zones, provinces and the central Ministry of Education and Department of Examination.

RECOMMENDATION 11: STEM ideas will be embedded in all relevant syllabuses and hence there is no need for a separate public examination for STEM. The existing public examination papers should be designed to evaluate engineering technology learning outcomes in addition to science and math related outcomes

RECOMMENDATION 12: A study to understand the SBA and Commissioner General of Examinations' periodic evaluations is needed to understand if there is a significance.

[9] Reference to the guidebook

4.1. Portfolio Assessment

Genuine evaluation is based on skills and knowledge developed throughout a course of study. Therefore, assessments tasks should look very similar to instructional tasks because assessments and instruction are inherently linked. Instructions in STEM classes are new teaching learning contexts created by teachers. These are contextually authentic. Portfolios are probably the most popular method of authentic assessment, which encourage students and teachers to value and explore multiple perspectives of learning, thinking and teaching. Portfolios are assembled in many ways (showcase, documentation, evaluation & process). Portfolios, as a method of alternative assessment practices, provide opportunities for the learning process to be documented and validated. The expanded view of what is validated and important in the learning process encourages teachers and students to explore new possibilities in the learning process. Portfolios constructed through a collaborative effort between the student and the teacher is meaningful to both parties.

Portfolio Assessment is a process by which you document acquired school-level learning from things that didn't necessarily happen in a classroom setting. **A portfolio is a collection of materials that provides evidence of that learning.**

The construction of meaningful and purposeful portfolio assessment would be based on five underlying elements namely, **1) collaboration, 2) an expanded view of learning, knowledge and problem solving 3) a place to view process, 4) exploration of multiple perspectives and solutions to a problem, 5) reflection and self-assessment.** Reflection provides opportunities to critically examine the experiences and products of the portfolio, as well as the interpretations of those experiences.

RECOMMENDATION 13: Collaborative Portfolio Assessment would be suited to complement SBA in STEM Assessment.

Assessing work in portfolios is not an easy task as giving a paper and pencil test with predetermined answers and scoring. Portfolios do not contain set standards, criteria and, ways to evaluate as do standardized testing practices. Based on the purpose of the activity teachers can develop a rubric. For example, a generalized 4-point task rubric in which a score of 4 demonstrates complete understanding, 3 demonstrates adequate understanding, 2 demonstrates limited understanding and, 1 demonstrates little or no understanding.

The development and use of portfolios in science ***(this applies to STEM)*** can be an important step in effectively assessing the knowledge, skills, attitudes and insights students gain in science. Scientific knowledge stretches beyond defining isolated terms and facts and incorporates an array of thinking skills and processes. The items in a science portfolio have the potential to encompass many components of the science curriculum. It is important to remember the goals and purposes for the activities and the portfolios.

RECOMMENDATION 14: Portfolio Assessment should have four point generalized task rubrics for qualitative assessments

5. TRAINING FOR TEACHERS AND ADMINISTRATORS

The success of the introduction of STEM depends on the involvement of the teacher, school administration and monitoring staff from the educational divisions, zones and provincial offices. Training needs to be activity-based rather than giving lectures, so that the participants will be able to expose themselves to real problems in classroom contexts. These activities should be based on STEM instruction and assessment. Unless they do work in collaboration, they will not be able to provide proper guidance for students and teachers. It will be a difficult task to conduct training to all stake holders in STEM, but it is required to reap the benefits of STEM introduction.

RECOMMENDATION 15: Develop STEM Master Trainers for Divisions, Zones and Provincial Offices
RECOMMENDATION 16: Develop School Teachers using Master Trainers by inducting them to the Portfolio Assessment Methods
RECOMMENDATION 17: The success of STEM transformation depends entirely of collaboration between STEM subject teachers and Administrators at all levels. Team work is an essential lesson to all in STEM and Administration. Structures and processes should be in place to sustain and enhance collaboration between administrators and teachers.

5.1. Harmonize and Synchronize Students Learning in STEM Subjects

New technology has made it possible for a person to speak to his mobile and produce a text message. He could also write a book by using his voice as the medium of communication with a mobile or a tab. Such technology was only a futuristic dream about five years ago. In a situation where speech to text is so simple it would be of less value to teach students how to use a typewriter or shorthand than to learn how to type on a mobile, tab or a laptop (besides, word processing rendered the typewriter obsolete). The extent to which students learn writing and the efforts at maintaining purity of script may be debatable. Recognition of letters and their meaning in word formation is of course essential. In similar vein, in STEM education some of the learning experiences may be rationalized and synchronized by emphasizing the learning on future relevant STEM. In time to come even rapid translation with proper grammar would become quite easy. It is available currently but grammatically accurate translation is still not practical. STEM learning would be facilitated by the learning English to access the knowledge on the web and exchange of ideas and training.

RECOMMENDATION 18: Teaching English in a contextually relevant sense is useful to STEM. Steps should be taken to improve teaching English.

Science and Mathematics are taught from Grade 6 to O Level. Then the streams separate. Science stream consists of Biological science or Physical Science. In Biological Science stream, students follow Biology, Chemistry and Physics (or Agriculture). Physical science stream includes Physics, Chemistry and Combined Mathematics. Technology stream students follow three subjects; Science for Technology, Engineering Technology or Bio-system technology and the third subject from 10 subjects including English, Information Technology, Economics, Geography, Commerce, Accounting, and Arts etc. This is taught in some selected schools in Sri Lanka from 2013. First batch of students sat GCE A/L examination in 2015, and they entered Universities in 2017.

Physical Science Stream is also known as Maths Stream. Mathematics Stream has four main subjects: Combined Mathematics, Physics and Chemistry and Information and Communication Technology (ICT). The new syllabus provides a choice between either Chemistry or ICT as subjects, Combined Mathematics and Physics are mandatory. Combined Mathematics is a combination of Pure Mathematics and Applied Mathematics. Previously, the students had to follow these two subjects separately. The curriculum also consists of practical experiments that students are expected to participate in school laboratories.

Biological Science Stream consists of three subjects: Biology, Chemistry, Physics, and Agricultural Science as an optional subject. Students can choose either Physics or Agricultural Science.

A reasonable study of the syllabuses in individual subjects, currently three, should be undertaken to ensure that the contents match with learning outcomes expected from STEM portfolio. As an example, if the subject of learning is ‘Power Generation’ at Grade 6 in Science then the content in the Mathematics I, Mathematics II, Science and Technology syllabi should be in harmony and synchronized. It means the topic has consistent or compatible content in all four and occur or exist at the same time of learning. Without such harmony and synchrony students will not gain the experience to connect with different learning areas.

RECOMMENDATION 19: The content of STEM subject syllabi should be studied in detail to develop portfolio assessments collaboratively to synchronize and harmonize the contents with the learning development.

NATIONAL SCIENCE FOUNDATION

6. SCIENCE STREAM

6.1. Availability of Science Teachers

The distribution of Science Teachers in the school system is given below

Year District Schools Teachers Provincial/National

6.2. Teachers' Training Science

The training programs conducted in the centres are as follows.

The rapidly increasing needs of STEM education will require changes to the training needs and changing the training syllabus. The purpose here is to bring the STEM subjects integration.

No of Teachers A/L Science Stream

	National Schools		Provincial Schools	
	Sinhala	Tamil English	Sinhala	Tamil English
Chemistry	647	104	683	41
Physics	612	116	607	41
Biology	479	64	616	27

Science Teachers Grades 6-11

National Schools	2,755
Provincial Schools	10,631
Total	13,386

Teacher Deficit/ Excess Science - A/L Teachers

	Provincial Schools		National Schools		
	Sinhala	Tamil	Sinhala	Tamil	Total
Biology	-92	-36	-149	-21	-298
Physics	-22	-33	-102	-13	-170
Chemistry	+306	+21	-13	-6	308

Teacher Deficit/Excess (6-11 Teachers) in Science

	Provincial Schools		National Schools	
	Sinhala	Tamil	Sinhala	Tamil
6-11 Teachers	43	-335	+531	+44

6.3. Performance of Students

Each class from Grade 6 up has a curriculum with outcomes of learning lessons.

E.g. The success rate of science in the schools are as follows

GCE O/L Performance in Science

Year	Pass Percentage (A+B+C+S)	Failed Percentage
2008	47.42	52.58
2009	44.24	55.76
2010	58.69	41.31
2011	62.01	37.99
2012	68.26	31.74
2013	67.53	32.47
2014	60.57	39.43
2015	68.02	31.98
2016	66.33	33.67

GCE A/L Performance of Science

	Pass Rate %				
	2012	2013	2014	2015	2016
Bio	53.85	49.87	50.30	51.65	53.26
Physical	44.78	47.17	46.60	48.03	53.35
Total	49.66	48.60	48.66	50.11	53.30

7. MATHEMATICS

Mathematics develops the analytical and logical thinking skills of a mind due to its abstract nature. Therefore, Mathematics is one of the key subjects in the school curriculum and it is taught in the primary grades from grade 1 to grade 5 as well as in the secondary grades. As an integrated curriculum is implemented at the primary level the same teacher teaches Mathematics along with other subjects in the respective grade. There are separate teachers for teaching Mathematics at the secondary level. The "Mathematics for all" policy has been implemented in the secondary grades from 6 to 11 since 1972.

> Mathematics is a weakness of many students, due to a multiplicity of reasons including its abstract nature and the teaching methods. Mathematics happens to be a practice for students later in life not through the learning of an abstract science but as an applied science, which is dealt in our STEM discussion.

> Four significant factors which need to be considered when selecting the mathematics content for secondary education in future curriculum revisions:
>
> (a) the realization that school Mathematics is not the same as academic or research Mathematics;
>
> (b) that secondary school Mathematics stands for helping students develop certain "life skills" that will enable them to become informed citizens;
>
> (c) the recognition of Mathematics as a support subject required for use in other subjects; and
>
> (d) the priority order of introducing mathematical concepts for more effective learning.

The Mathematics curriculum in the secondary grades was developed based on five aims of developing mathematics skills as follows.

(1) **Computational Skills**: The development of computational skills through the provision of mathematical concepts and principles, as well as knowledge of mathematical operations, and the development of the basic skills of solving mathematical problems with greater understanding.

(2) **Math Communication Skills**: The development of correct communication skills by enhancing the competencies of the proper use of oral, written, pictorial, graphical, concrete and algebraic methods.

(3) **Intradisciplinary Skills:** The development of connections between important mathematical ideas and concepts, and the use of these in the study and improvement of other subjects. The use of mathematics as a discipline that is relevant to lead an uncomplicated and satisfying life.

(4) **Reasoning Skills:** The enhancement of the skills of inductive and deductive reasoning to develop and evaluate mathematical conjectures and conversations.

(5) **Modelling Skills:** The development of the ability to use mathematical knowledge and techniques to formulate and solve problems, both familiar and unfamiliar and which are not limited to arithmetic or the symbolical or behavioural, which arise in day to day life.

RECOMMENDATION 20: In view of the five targeted skills in Math teaching a study has to be done to improve on outcomes since there are many students who fail in Math

Further, in the mathematics curriculum two kinds of standards were identified as content and process standards aligned with the standards of Mathematics introduced by the National Council of Teachers of Mathematics (NCTM) which was recognized as a global benchmark by many leading international educational jurisdictions ((McCaul, 2007). **There are five process standards; knowledge and skills, communication, identifying relationships, reasoning and problem solving. The six content standards are numbers, measurements, algebra, geometry, statistics, sets and probability.** There are 31 common competencies identified for grades 6 to 11 in the math curriculum. For each competency, competency levels, content, learning outcomes and number of periods are given in the syllabus. The competencies vary from grade to grade as illustrated in the table 1 below.

Table 1. Structure of the math curriculum in the secondary grades

Grade	Competency	Competency levels	Learning Outcomes
6	19	36	142
7	27	38	263
8	28	41	206
9	24	39	85
10	25	55	239
11	19	43	304
Source: National Institute of Education			

Combined Mathematics is taught at G.C.E. (A/L) classes as one of the subjects under Physical Science streams. Other than that, Mathematics and Higher Mathematics are taught in G.C.E. (A/L) classes in different subject combinations.

NATIONAL SCIENCE FOUNDATION

7.1. Performance of Math Students

Current student population in government school system is 4,143,330 (School census report – 2016). Out of these students 1,933,486 (46%) are studying Mathematics as compulsory subject at secondary level and 36,893 (1.9%) are studying combined mathematics in the G.C.E. (A/L) classes.

Mathematics is evaluated as one of the 9 subjects at the G.C.E. (O/L) examination and Combined Mathematics is evaluated at the G.C.E (A/L) at the National level. Besides this, term tests are conducted at the school level and the achievement of students in Mathematics are assessed through School Based assessments. In addition, the National Education Research and Evaluation Centre (NEREC) in the University of Colombo conducts national assessment for grades 4 and 8 to assess different subjects and Mathematics includes in both assessments.

The following table 2 and 3 depict the performance of students in Mathematics and Combined Mathematics at G.C.E. (O/L) and A/L examinations respectively for six consecutive years.

Table 2. Pass percentage of Mathematics at G.C.E (O/L)

Year	No. Sat	A+B+C+S	%
2011	269167	148940	55.33%
2012	267858	148261	55.35%
2013	264117	151190	57.23%
2014	256800	145602	56.70%
2015	272723	150481	55.18%
2016	285537	179346	62.81%
Source: Department of Examinations			

Table 3. Pass percentage of Combined Mathematics at G.C.E (A/L)

Year	**Pass Percentage**
2011	48.60
2012	50.45
2013	54.75
2014	52.51
2015	53.16
2016	62.00
Source: Department of Examinations	

Performance of students in grades 4 and 8 is revealed by the relevant studies done by NEREC and shown in the table 4 and 5.

Table 4. Disparities in student performance revealed by the NEREC study (Grades 4 and 8)

Grade	Year	All Island Mean Value	Mean score									
			School Type				Gender		Medium		Location	
			1AB	1C	T2	T3	M	F	S	T	R	U
4	2015	62.25	67.66	60.04	57.87	64.23	60.35	64.16	65.34	54.76	59.56	66.97
	2013	60.32	62.2	61.33	59.51	59.83	58.34	62.45	63.32	50.93	59.38	60.32
8	2016	51.11	58.14	44.97	42.32	-	49.40	52.70	53.28	45.01	57.38	48.75
	2014	50.87	58.70	42.37	41.54	-	49.31	52.33	53.13	44.37	58.75	46.79
Source: NEREC reports M-Male, F-Female												

Table 5. Sub skills related disparities in student performance revealed by the NEREC study (Grades 4 and 8)

Grade	Year	Facility Index				
		Concepts		Procedures		Problem
4	2015	56.75		67.74		57.98
	2013	65.99		60.8		53.14
8	Year	Knowledge & skills	Communication	Relationships	Problem Solving	Reasoning
	2016	50.1	52.09	55.85	49.75	64.75
	2014	49.4	51.2	54.6	48.45	65.7
Source: NEREC reports						

7.2. Availability of Mathematics Teachers

Mathematics teachers are recruited in two ways as teachers who are passed out from National Colleges of Education (NCOES) for grades 6 to 11 and graduate teachers for GCE (A/L) classes. The total approved teacher cadre for Mathematics is 14,870 which consists of 13,329 of teachers for grades 6 to 11 and 1541 of Combined Math teachers. However, there are only 13,948 of Math teachers in the system at present as 12,875 for grades 6 to 11 and 1073 of Combined Math teachers. Though the difference between the approved cadre and available cadre is 922 the actual shortage of Mathematics teachers in the system is 3801 due to teacher deployment issues. Other than that, 2993 of teachers who were appointed for other subjects (Non-Math teachers) are teaching Mathematics in schools. The following table 6 illustrates supply of Math teachers from the NCOEs and the number of attritions in the relevant year which shows that there is a gap between the recruitment and the attrition in the Sinhala medium.

RECOMMENDATION 21: The high level of attrition among NCoE Math teacher recruits has to be studied for remedial action.

NATIONAL SCIENCE FOUNDATION

Table 6. Mathematics Teachers supplied by NCoEs and teacher attrition of Mathematics.

Year	Sinhala		Tamil	
	Supplied by NCOE	Attrition	Supplied by NCOE	Attrition
2013	130	361	56	32
2014	130	393	44	48
2015	160	390	76	53
2016	145	261	43	34
2017	161	286	32	35
Source: Ministry of Education				

7.3. Teachers' Training

Normally, the National Institute of Education trains the In-Service Advisors (ISAs) and the relevant resource persons in relation to curriculum changes as well as modifications and the provinces conduct training programmes for teachers according to the guidelines provided by the National Institute of Education (NIE).

7.4. Comments on Mathematics Education

There are several key studies conducted on Mathematics education in schools. The major recommendations and suggestions of those studies are as follows.

a) The secondary school curriculum needs to be sufficiently differentiated to consider heterogeneity among students.

b) Teacher education and training programs need to incorporate the objectives of the mathematics curriculum so that all teachers will have a better understanding of the expectations of the curriculum.

c). To overcome shortcomings in the Teacher Instruction Manuals (TIMs), learning outcomes need to be provided not only for the content standards but for the process standards as well. The process standards reasoning and problem solving need to be included in the activities.

d). Teachers play an especially important role in providing students with a high-quality mathematics education. In consequence, it is essential to ensure that all mathematics teachers are subject-competent and have sound teaching practices.

(1. Transforming school education in Sri Lanka from Cut Stones to Polished Jewels, The World bank, 2011

NATIONAL SCIENCE FOUNDATION

2. Strengthening Mathematics education in Sri Lanka, South Asia: Human Development Unit, The World Bank, July 2011)

e). The issue of the shortage of qualified and competent mathematics teachers especially in rural and underprivileged schools must be addressed without any further delay.

f). The Bachelor of Education (BEd) degree with Mathematics specialization offered by the NIE, the Diploma course conducted by the National Colleges of Education (NCoEs) and In-service education programmes should be reviewed, revised and efficiently conducted to ensure that knowledgeable and competent teachers are produced.

g). A consolidated teacher training/education/development plan should be prepared for mathematics teachers, ISAs and Teacher Educators

h). The mathematics curriculum from Grade 1 to 11 needs to be properly integrated vertically between the primary and secondary cycles by considering the depth of the content and the ability of average learners to grasp those concepts.

i). There are four significant factors which need to be considered when selecting the mathematics content for secondary education in future curriculum revisions: (a) the realization that school Mathematics is not the same as academic or research Mathematics; (b) that secondary school Mathematics stands for helping students develop certain "life skills" that will enable them to become informed citizens; (c) the recognition of Mathematics as a support subject required for use in other subjects; and (d) the priority order of introducing mathematical concepts for more effective learning. Apart from this, the importance of knowing the conventional multiplication tables should be emphasized in the primary curriculum, due to significant proven benefits of learning them in the past and the detrimental effect of not emphasizing it in the current content.

RECOMMENDATION 22: Differentiating the secondary level Math teaching from higher level is essential. A review of Math curricula for secondary level is timely. The question is how do we make learning Math a fun experience?

j). As a possible remedial solution to the current situation of the same mathematics being learned by all, it is recommended to identify Essential Learning Concepts (ELCs) in the syllabi of Grades 10 & 11 and It is also recommended to reach consensus on the expected Basic (Lowest) Achievement Level (BAL),

k). To fully align the O/L Mathematics question papers with the curriculum, instructions and learning tools, it is recommended to prepare a mathematics evaluation framework document that lays out the basic design of the question paper.

(The Report of the Special Advisory Committee for Submission of Suitable Recommendations to Improve Mathematics Performance of Students at the GCE (O/L) Examination, 10th September 2014)

8. ENGINEERING AND TECHNOLOGY EDUCATION

Engineering is broadly understood as the process used in advancing the human condition using the scientific knowledge. The American Engineers' Council's (AEC) definition brings multidisciplinary nature of Engineering into limelight. It speaks about Functionality, Economics, and Safety.

The definition of "engineering" given by the American Engineers' Council for Professional Development is as follows.

The creative application of scientific principles

- to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; OR
- to construct or operate the same with full cognizance of their design; OR
- to forecast their behaviour under specific operating conditions;

all with respect to an intended function, economics of operation and safety to life and property.

Because of the aspects indicated in the last phrase (which probably should include the *"preservation of environment"*) of the AEC definition, engineering may be viewed as a bridge between the sciences and humanities. The discussion on the gaps in learning of STEM will take up this extended scope of STEM education.

A much simpler and a straightforward definition is used by the National Research Council (NRC), Washington, DC, in developing K-12 educational frameworks; viz. *Engineering is a systematic and often iterative approach to designing objects, processes, and systems to meet human needs and wants.*

Professional engineers engage in the activities indicated in the above definition in solving real world problems. They primarily use their knowledge and skills in science and mathematics in this exercise. Always, their choice of solutions is restricted by constrains which may be economic, political, ethical, environmental and social.

8.1. Observation 1:

STEM subject curricula should provide opportunities for students to solve real world problems through designing objects, processes and systems under a set of constrains and to improve the solutions iteratively.

Definition of two closely related terms

NRC uses the following definitions for two closely related terms, "technology" and "application of science" which may be useful in designing STEM curricula.

Technology *is any modification of the natural world made to fulfil human needs or desires.*

An application of science *is any use of scientific knowledge for a specific purpose, whether to do more science; to design a product, process, or medical treatment; to develop a new technology; or to predict the impacts of human actions.*

According to the above definitions, one may interpret technology as a product of engineering and engineering is a subset of applications of science.

Three general principles for K–12 engineering education. Standards for K-12 Engineering Education in USA (Ref. 2) identifies three general principles that should be used in guiding K-12 engineering education.

> ***Principle 1****.* *K–12 engineering education should emphasize engineering design.*
>
> ***Principle 2.*** *K–12 engineering education should incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills.*
>
> ***Principle 3.*** *K–12 engineering education should promote engineering habits of mind.*

Engineering habits of mind align with what many believe are essential skills for citizens in the 21st century. These include

(1) Systems thinking,

(2) Creativity,

(3) Optimism,

(4) Collaboration,

(5) Communication, and

(6) Attention to ethical considerations.

Observation 1 above has dealt with principle 1. Principle 2 is embedded in any STEM curriculum.

RECOMMENDATION 23: STEM should include the K12 principles, to provide opportunities for students to solve real world problems through designing objects, processes and systems under a set of constrains and to improve the solutions iteratively.

8.2. Observation 2:

STEM subject curricula should provide opportunities for students to develop engineering habits of mind.

Three dimensions of science and engineering education

A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (Ref. 1) uses three dimensions in science and engineering education which are indicated below, in verbatim.

Dimension 1: Scientific and Engineering Practices

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analysing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Dimension 2: Crosscutting Concepts

1. Patterns
2. Cause and effect: Mechanism and explanation
3. Scale, proportion, and quantity
4. Systems and system models
5. Energy and matter: Flows, cycles, and conservation
6. Structure and function
7. Stability and change

Dimension 3: Disciplinary Core Ideas

Physical Sciences

PS1: Matter and its interactions
PS2: Motion and stability: Forces and interactions
PS3: Energy
PS4: Waves and their applications in technologies for information transfer

Life Sciences

LS1: From molecules to organisms: Structures and processes
LS2: Ecosystems: Interactions, energy, and dynamics
LS3: Heredity: Inheritance and variation of traits
LS4: Biological evolution: Unity and diversity

Earth and Space Sciences

ESS1: Earth's place in the universe
ESS2: Earth's systems
ESS3: Earth and human activity

Engineering, Technology, and Applications of Science

ETS1: Engineering design
ETS2: Links among engineering, technology, science, and society

NATIONAL SCIENCE FOUNDATION

8.3. Observation 3:

Dimensions 2 and 3 mainly involve concepts related to subjects. At least in the short run we may not have much choice other than using the available science books published by the Government Publications Department. However, ideally, some content development may be "necessary for engineering, technology and applications of science", i.e. ETS1 and ETS2 above or an equivalent.

Comparison of science and engineering practices

To see the role in Dimension 1 in curriculum it is necessary to examine them in detail. I have reproduced below the exposition made by Roger W. Bybee (Ref. 4). This comparison gives insight to the nature of engineering practices in comparison with the more familiar practices in science.

1. Asking questions and defining problems	
Science begins with a question about a phenomenon such as "Why is the sky blue?" or "What causes cancer?" A basic practice of the scientist is the ability to formulate empirically answerable questions about phenomena to establish what is already known, and to determine what questions have yet to be satisfactorily answered.	**Engineering** begins with a problem that needs to be solved, such as "How can we reduce the nation's dependence on fossil fuels? or "What can be done to reduce a particular disease? or "How can we improve the fuel efficiency of automobiles? A basic practice of engineers is to ask questions to clarify the problem, determine criteria for a successful solution, and identify constraints.

2. Developing and using models	
Science often involves the construction and use of models and simulations to help develop explanations about natural phenomena. Models make it possible to go beyond observables and simulate a world not yet seen. Models enable predictions of the form "if…then… therefore" to be made to test hypothetical explanations.	**Engineering** makes use of models and simulations to analyze extant systems to identify flaws that might occur, or to test possible solutions to a new problem. Engineers design and use models of various sorts to test proposed systems and to recognize the strengths and limitations of their designs.

3. Planning and carrying out investigations	
Scientific investigations may be conducted in the field or in the laboratory. A major practice of scientists is planning and carrying out systematic investigations that require clarifying what counts as data and in experiments identifying variables.	**Engineering investigations** are conducted to gain data essential for specifying criteria or parameters and to test proposed designs. Like scientists, engineers must identify relevant variables, decide how they will be measured, and collect data for

	analysis. Their investigations help them to identify the effectiveness, efficiency, and durability of designs under different conditions.

4. Analysing and interpreting data	
Scientific investigations produce data that must be analyzed to derive meaning. Because data usually do not speak for themselves, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data. Sources of error are identified and the degree of certainty calculated. Modern technology makes the collection of large data sets much easier providing secondary sources for analysis.	**Engineering investigations** include analysis of data collected in the tests of designs. This allows comparison of different solutions and determines how well each meet specific design criteria—that is, which design best solves the problem within given constraints. Like scientists, the engineers require a range of tools to identify the major patterns and interpret the results. Advances in science make analysis of proposed solutions more efficient and effective.

5. Using mathematics and computational thinking	
In **science**, mathematics and computation are fundamental tools for representing physical variables and their relationships. They are used for a range of tasks such as constructing simulations; statistically analysing data; and recognizing, expressing, and applying quantitative relationships. Mathematical and computational approaches enable prediction of the behaviour of physical systems along with the testing of such predictions. Moreover, statistical techniques are also invaluable for identifying significant patterns and establishing correlational relationships.	In **engineering**, mathematical and computational representations of established relationships and principles are an integral part of the design process. For example, structural engineers create mathematical-based analysis of designs to calculate whether they can stand up to expected stresses of use and if they can be completed within acceptable budgets. Moreover, simulations provide an effective test bed for the development of designs as proposed solutions to problems and their improvement, if required.

6. Constructing explanations and designing solutions	
The goal of **science** is the construction of theories that provide explanatory accounts of the material world. A theory becomes accepted when it has multiple independent	The goal of **engineering** design is a systematic solution to problems that is based on scientific knowledge and models of the material world. Each proposed

lines of empirical evidence, greater explanatory power, a breadth of phenomena it accounts for, and has explanatory coherence and parsimony.	solution results from a process of balancing competing criteria of desired functions, technical feasibility, cost, safety, aesthetics, and compliance with legal requirements. Usually there is no one best solution, but rather a range of solutions. The optimal choice depends on how well the proposed solution meets criteria and constraints.

7. Engaging in argument from evidence	
In **science**, reasoning and argument are essential for clarifying strengths and weaknesses of a line of evidence and for identifying the best explanation for a natural phenomenon. Scientists must defend their explanations, formulate evidence based on a solid foundation of data, examine their understanding considering the evidence and comments by others, and collaborate with peers in searching for the best explanation for the phenomena being investigated.	In **engineering**, reasoning and argument are essential for finding the best solution to a problem. Engineers collaborate with their peers throughout the design process. With a critical stage being the selection of the most promising solution among a field of competing ideas. Engineers use systematic methods to compare alternatives, formulate evidence based on test data, make arguments to defend their conclusions, critically evaluate the ideas of others, and revise their designs to identify the best solution.

8. Obtaining, evaluating, and communicating information	
Science cannot advance if scientists are unable to communicate their findings clearly and persuasively or learn about the findings of others. A major practice of science is thus to communicate ideas and the results of inquiry— orally; in writing; with the use of tables, diagrams, graphs and equations; and by engaging in extended discussions with peers. Science requires the ability to derive meaning from scientific texts such as papers, the internet, symposia, or lectures to evaluate the scientific validity of the information thus acquired and to integrate that information into proposed explanations.	**Engineering** cannot produce new or improved technologies if the advantages of their designs are not communicated clearly and persuasively. Engineers need to be able to express their ideas orally and in writing; with the use of tables, graphs, drawings or models; and by engaging in extended discussions with peers. Moreover, as with scientists, they need to be able to derive meaning from colleagues' texts, evaluate information, and apply it usefully.

RECOMMENDATION 25: Content development is necessary for engineering, technology and applications of science

8.4. Observation 4:

It is desirable that the science and engineering practices be understood by the students by engaging in them. As such the activities in the curriculum should be designed so that the students get an opportunity to practice them.

An example of engineering and technology learning outcomes.

2016 Massachusetts Science and Technology/Engineering Curriculum Framework (Ref. 5) lists an extensive set of outcomes for Science and Technology/Engineering education. I have reproduced below the learning outcomes in engineering and technology for Grade 6.

ETS1. Engineering Design

1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution. Include potential impacts on people and the natural environment that may limit possible solutions.
2. Create visual representations of solutions to a design problem. Accurately interpret and apply scale and proportion to visual representations.

Clarification Statements:

- Examples of visual representations can include sketches, scaled drawings, and orthographic projections.
- Examples of scale can include ¼" = 1'0" and 1 cm = 1 m.

3. Communicate a design solution to an intended user, including design features and limitations of the solution.

Clarification Statement:

- Examples of intended users can include students, parents, teachers, manufacturing personnel, engineers, and customers.

RECOMMENDATION 26: STEM Subjects Curricula should be designed so that the students get to practice by engaging in different activities.

9. TECHNICAL EDUCATION (THIS IS NOT TECHNOLOGY EDUCATION)

Technical Education relates to providing the skills required for the world of work. **Technology** is the application of scientific knowledge for practical purposes, especially in industry

UNESCO and ILO recommendations (2002) identify the purpose of initiation to technological education within general education as "to broaden educational horizons by serving as an introduction to the world of work, and the world of technology and its products through the exploration of materials, tools, techniques and the process of the production, distribution and management as a whole, and to enrich the learning process through practical experience" This is demonstrated by many countries by introducing technical subjects and technology streams in the secondary and upper secondary education.

The group of technical subjects at the G.C.E. O/L in Sri Lanka offered to all students provides some initiation to the world of work and the world of technology.

9.1. Technical Subjects in the general education system

Grade 6-9: Practical and Technical skills

Technical Education is taught in schools as a subject named **Practical and Technical Skills** from grade 6-9, that is consisting of five main disciplines, agriculture, food, elementary technology, business matters and graphics. ICT is also integrated in all subject areas.

The five technical areas in grade 6 and 7get reduced to four in in grades 8&9with graphics area being integrated with other 4 areas. Projects representing all 4 areas are introducing in grade 9, the number of projects to be completed during the year is 8.

Grade 10-11: Technical Subjects

- Agriculture and Food Technology
- Aquatic Bio-resources Technology
- Home Economics
- ICT
- Art and Crafts
- Design and Construction Technology
- Design and Electrical and Electronics Technology
- Design and Mechanical Technology

G. C. E. Advanced Level

Technology stream has been introduced in 2013 under two wide technological fields and the students can select one subject out of the two "Engineering Technology" and "Bio systems Technology". Further students have the opportunity of studying the fundamentals

NATIONAL SCIENCE FOUNDATION

of Mathematics, Science, ICT required for the selected technological subject through the "Science for Technology", which is the second subject of this stream. The third subject which belongs to the Technological stream is one selected subject out of 10 subjects prescribed for the A/L now.

The technology related subjects in the existing system

- Agricultural Science
- ICT
- Home Economics
- Soft Technology
- Hard Technology } Under the art stream/ very less no. of students are studying

Teacher Availability and Basic Data

G. C. E. O/L

Subjects (O/L)	No of Students	No of Schools	No of Teachers
Practical Technical Skills (6-9)	824977	4133	4192
Agric & Food Technology (10-11)	112121	3923	3133
Aquatic Bio resources (10-11)	1969	104	75
Home Economics	93562	3512	3352
ICT	304853	3406	3910
Other Technical subjects	101117	1493	1338

G.C.E. A/L

Subjects (A/L)	No of Students	No of Schools	No of Teachers
Agricultural Science	17146	852	416
Bio systems Technology	14965	358	286
Engineering Technology	22971	370	327
ICT	22234	746	460
Home Economics	10070	863	344

NATIONAL SCIENCE FOUNDATION

G.C.E. A/L Technology Stream

Subject	No. of teachers
Bio systems Technology	557
Engineering Technology	529
Science for Technology	481

Results – Technology Stream – (As separate subjects)

Subject	2015 (%)	2016 (%)
Engineering Technology	71.84	83.80
Bio system Technology	83.37	84.01
Science for Technology	69.96	68.67

Results – Technology Stream (All 3 subjects passed)

Subject	2015 (%)	2016 (%)
Engineering Technology	50.09	55.58
Bio system Technology	60.66	55.58

Teacher Training

Teacher training and development programs are conducted by the Ministry of education, NIE and by the provincial Departments of Education in collaboration with relevant institutions of Tertiary and Vocational Education and Training (TVET) and universities.

Comments on Technological Education

A study conducted by University of Colombo in 2016, revealed the following problems and obstacles to implement the technology stream

1. Student enrolment

The no of students enrolled in the technology stream surpasses all other streams in 2013. This number was even greater in 2014. This is a very positive trend. According to the high demand. who have good O/L results are also applied to do A/L technology stream without applying for the science stream. Therefore, the objective of introducing the technology stream could not have been better achieved.

2. Awareness programmers

Though introductory programmes have been conducted by schools for students, teachers and parents, most of the programmes have been on technology subjects and those on vocational guidance is less.

3. Entry requirement

Majority of the teachers claim that a pass in science and maths at O/L is not adequate to follow the Technology stream and there appears to be a mismatch between the entry requirements and subject content.

4. Availability of Human resources

There is a shortage of teachers for Engineering Technology and Science for technology subjects. The current policy is that G.C.E. A/L subjects should be taught by graduates, but there are less than 20% graduates to teach Engineering technology.

5. Inadequate practical training

Majority of the teachers claim that they need more training on practical activities specially in the relevant TVET sector institutions.

6. Equipment

Majority of the teachers claim that equipment is not sufficient

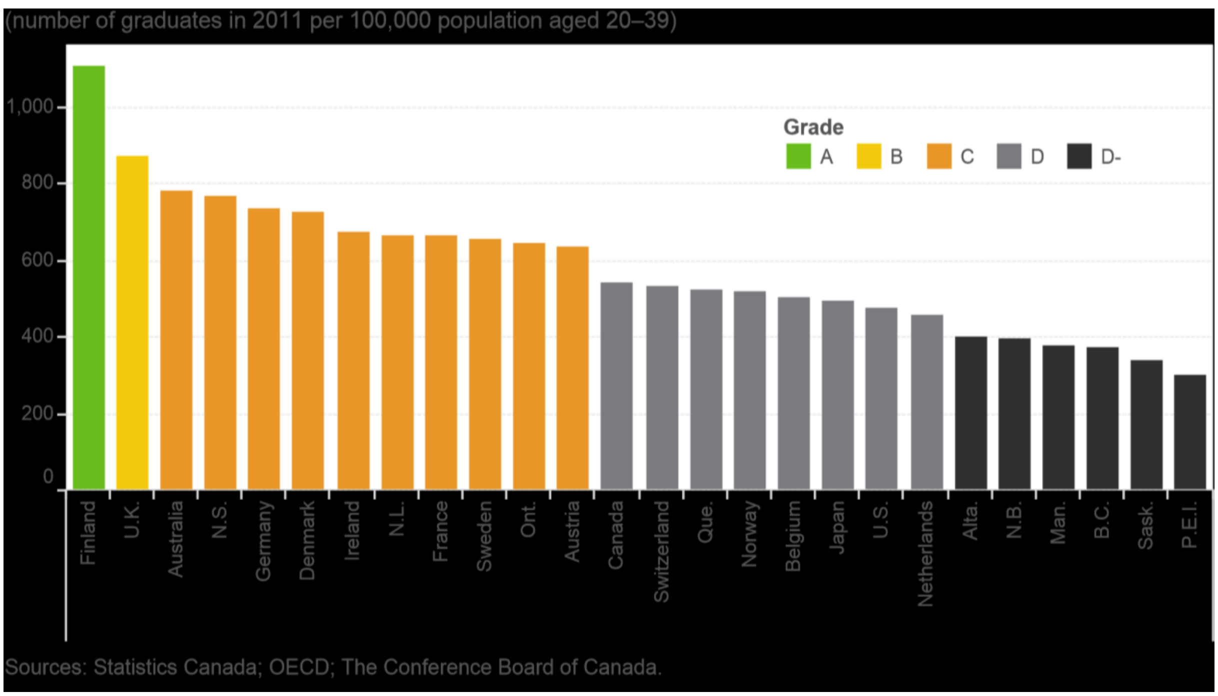
NATIONAL SCIENCE FOUNDATION

10. STEM PERFORMANCE IN OTHER COUNTRIES

STEM is one of the main trends in global education picking up more students annually. In view of the 4th Industrial Revolution precipitated by the rapid Technology Revolution in the new millennium, most jobs today will disappear giving rise to new jobs based on STEM in the next decade. For example, in EU countries, the share of employed professionals in this area has increased by 12% from 2000 to 2013. Also, in European countries it is predicted that the demand for STEM professionals will grow by 8% by 2025, whereas the demand for other professions will grow only by 3%[10].

In 2011, among 16 OECD countries under consideration, Finland had the highest number of graduates of STEM-professions: 1,109 per 100,000 citizens aged 20-39 years. This figure is twice higher than in Canada and Switzerland[11].

Figure 6 Science, Maths, Computer Science and Engineering Graduates, Provinces of Canada and International Peers 2011

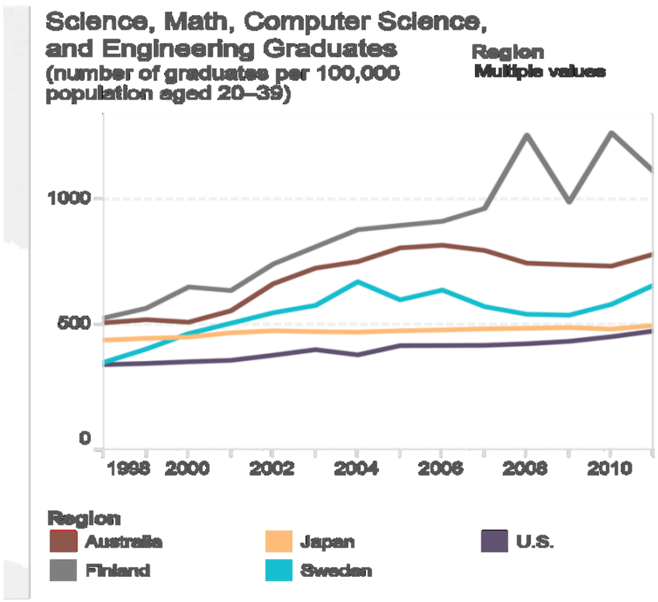


[10] http://www.cedefop.europa.eu/en/publications-and-resources/statistics-and-indicators/statistics-and-graphs/rising-stems

[11] Source: Conference Board of Canada, Graduates in Science, Math, Computer Science, and Engineering http://www.conferenceboard.ca/hcp/provincial/education/sciencegrads.aspx

The trends in four important countries in STEM qualified graduates can be seen in the figure below.

Figure 7: STEM Trends in 4 leading countries



As it is Finland is leading the way (striving to get more recent information).

As we have learnt from the experience of our own graduates in Sri Lanka it has been well understood by the international community that having STEM skills is no longer sufficient on its own. Graduates at all levels, including those from upper-secondary VET, need personal and behavioural attributes as well as STEM-related skills[12]. Creativity, team working, communication and problem solving are needed as scientific knowledge and innovation is increasingly produced by teams that often combine different nationalities as well as different organisations and enterprises. Understanding the application of new technologies in everyday life presents new challenges. In many cases it is not enough that something works well. It should also be well-designed, stylish and desirable for more than just practical features.

RECOMMENDATION 27: STEM Subjects have to be taught in conjunction with other chosen subjects such as English, Aesthetics, Economics along with behavioral and essential skills that should be included.

Quoting from Cedefop.Europa[9] report "Between now and 2025, around two-thirds of the anticipated job openings in STEM-related professions will be to replace people working in these areas but who will retire. Currently, around 48% of STEM-related occupations require medium (upper-secondary) level qualifications, many of which are acquired through initial upper-secondary level VET. This figure is forecast to fall a little to around 46% in 2025 but, despite the image of highly-educated scientists in white coats, most STEM-related occupations will still require medium-level qualifications over the next decade or so." Unquote

Thus, in Sri Lanka any efforts to introduce STEM education would be considered a great benefit to the economy.

---

[12] (3) European Commission (2012) Assessment of impacts of NMP technologies and changing http://ec.europa.eu/research/industrial_technologies/pdf/nmp-skills-report_en.pdf

NATIONAL SCIENCE FOUNDATION

11. STEAM

STEAM gets this A added to STEM due to several reasons. Students need multidisciplinary exposure and mindset developed to approach solutions in a real world situation. Often silo based thinking prevents the interaction among the scientists and conservative approaches in sharing knowledge and resources in addressing problems. Therefore, A brings the concept of Aesthetics and Arts into the STEM education. By the time students reach the grade 6 already they have received lessons in Aesthetics which needs to be developed alongside STEM subjects to give the right mindset. We are not striving to present examples from around the world as this is accepted as much as STEM is an accepted norm in education.

11.1. Economics in STEM

During our discussions, it became clear to us that Economics would be of immense value to the STEM learner. The AEC has Economic value attached to designs in their fundamental definition of Engineering as mentioned earlier (pg32). This is another idea that we need to pursue in the reforms.

11.2. English Language in STEM

Globalization has trended towards making English our best communicating medium with the world. As STEM becomes introduced to the students it is also equally important to administer English learning in a manner that will keep pace with the learning of STEM subjects. This is specifically to impress upon the reader on the need to introduce English learning as an essential skill and not to be meant as a painful exercise.

12. References

1. McCaul, T. (2007). Study of the Implementation of Mathematics and Science Curriculum in Grade 6 and 10, National Institute of Education, Sri Lanka.
2. NEREC (2013), National Assessment of Achievement of Grade 4 Students in Sri Lanka, National Education Research and Evaluation Centre, University of Colombo, Sri Lanka
3. NEREC (2014), National Assessment of Achievement of Grade 8 Students in Sri Lanka, National Education Research and Evaluation Centre, University of Colombo, Sri Lanka
4. NEREC (2015), National Assessment of Achievement of Grade 4 Students in Sri Lanka, National Education Research and Evaluation Centre, University of Colombo, Sri Lanka
5. NEREC (2016), National Assessment of Achievement of Grade 8 Students in Sri Lanka, National Education Research and Evaluation Centre, University of Colombo, Sri Lanka
6. Strengthening Mathematics education in Sri Lanka, South Asia: Human Development Unit, The World Bank, July 2011
7. The Report of the Special Advisory Committee for Submission of Suitable Recommendations to Improve Mathematics Performance of Students at the GCE (O/L) Examination, 10th September 2014
8. Transforming school education in Sri Lanka from Cut Stones to Polished Jewels, The World bank, 2011
9. A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. The National Academies Press, Washington, DC, (2012).
10. Standards for K-12 Engineering Education, The National Academies Press, Washington, DC, (2010).
11. Pathote, P and Pandey, K., 2015, *Need of Non-Technical Content in Engineering Education*, IOSR Journal of Research & Method in Education (IOSR-JRME), Volume 5(2) Ver. I (Mar - Apr. 2015), pp 41-43 http://www.iosrjournals.org/iosr-jrme/papers/Vol-5%20Issue-2/Version-1/H05214143.pdf
12. Bybee, R. W., 2011, Scientific and Engineering Practices in K–12 Classrooms. Understanding A Framework for K–12 Science Education http://nstahosted.org/pdfs/ngss/resources/201112_framework-bybee.pdf
13. 2016 Massachusetts Science and Technology/Engineering Curriculum Framework, Massachusetts Department of Elementary and Secondary Education, 75 Pleasant Street, Malden, MA, USA http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf.